Mineral Nutrition of Feedlot Cattle

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Take-Home Message

Although minerals make a small contribution as a percentage of feedlot diets, they have a significant impact on cattle health and performance. Minerals are involved in essential body functions such as the immune system, reproduction, lactation, growth performance, bone growth, and hoof health. Animal productivity and health can be negatively impacted by both dietary deficiencies and excesses of minerals. A focus towards balancing feedlot diets to meet but not exceed nutrient requirements, decrease the environmental impact of intensive livestock production, while also placing an emphasis on maximizing efficiency of production has led to an effort in refining the mineral requirements of beef cattle.

The Nutrient Requirements of Beef Cattle (NRC, 2000) is the primary reference used by nutritionists for diet formulation. A 2007 survey of consulting feedlot nutritionists revealed that the beef NRC, various editions, serves as the main source of information for beef cattle requirements (69 %), with the majority of the remaining respondents indicating they utilize a combination of NRC recommendations and other information such as refereed journal articles or company databases (Vasconcelos and Galyean, 2007). The most recent update of the beef NRC was in 2000 and considerable research has been conducted since to improve upon mineral recommendations. An overview of each essential mineral is beyond the scope of this paper; instead, there will be a focus on highlighting the research on key minerals that have been given the greatest interest since last publication of the beef NRC (2000). Although progress has been made in the area of mineral nutrition 2000, further research will be necessary in this area to better understand the underlying mechanisms of mineral metabolism and to continue to improve upon current recommendations for beef cattle.

Macro-minerals

Minerals are categorized as macro- or micro-(trace) minerals depending on the amount of mineral required in the diet. The essential macro-minerals for beef cattle are calcium (Ca), phosphorus (P), potassium (K), sodium (Na), chlorine (Cl), and sulfur (S). Of the macro-minerals, P and S have been given the most attention in recent years. The focus on P has been primarily driven by increased awareness of the environmental impact of excess P coupled with increases in the cost of supplemental P. Wide-spread availability and use of ethanol co-products has resulted in higher dietary S than was experienced previously and resulted in a considerable body of work on the impact of high S levels on animal health and performance.

Phosphorus

Phosphorus plays a role in a number of critical body processes including the transfer of energy within cells as a component of Adenosine 5'-triphosphate, cell signaling, and is a component of deoxyribonucleic acid and ribonucleic acid. In the past, supplemental P was added to diets above the requirement as a low-cost insurance policy against the potential for deficiency;

however, in recent times the price of supplemental P has become prohibitive and there has been an increased awareness of the impact of excess P on the environment.

Phosphorus runoff from livestock operations is an environmental concern due to its role in eutrophication, the excessive growth of aquatic autotrophs, which include algae varieties and aquatic vascular plants, as a consequence of excess input of nutrients into a body of water (Kalff, 2002). Algae growth in moderate amounts is important to maintain ecosystems, but in excess results in decreased water quality. The toxins produced by some varieties of algae have been linked with sickness in humans as a result of contact with polluted water or fish from these environments.

Although a number of sources contribute to P pollution of water, including waste water treatment facilities and residential lawn fertilization practices, animal agriculture is often the first target of the media and law makers. Popular press primarily focused on the impact of manure nutrient runoff in their coverage of the July, 2013 Toledo, OH water-drinking ban. This ban was linked to the toxin microcystin which was produced by algae blooms on Lake Erie. Ohio also recently signed a bill that will require farmers to acquire fertilizer licenses to spread manure. A proactive approach from cattle feeders will be necessary to minimize the impact of intensive cattle feeding operations on the surrounding environment and also reduce the need for increased regulatory pressure.

The beef NRC (2000) estimates the maintenance P requirement to be 16 mg of absorbed P/kg of body weight (BW) and the requirement for gain as 3.9 g absorbed P per 100 g retained protein (NRC, 2000); however, there are a number of studies suggesting the P requirement for finishing cattle is overestimated by the beef NRC (Erickson et al., 1999; Erickson et al., 2002; Geisert et al., 2010). Yearling steers receiving a grain-based diet containing 0.14, 0.19, 0.24, 0.29 or 0.34 P as a percentage of DM showed no differences in growth performance, carcass characteristics, or ossification of bone tissue (Erickson et al., 1999). Thus, Erickson et al., (1999) suggested that P requirements for yearling steers fall below 15.9 g/d (0.14 % of DM) as compared to the 22.5 g/d P (0.20 % of DM) recommended by the NRC (2000). Similarly, the P requirement for calf-fed steers was found to be less than 14.2 g/d (0.16 % of DM) while the beef NRC (2000) estimated a requirement of 19 g/d (0.22 %) (Erickson et al., 2002). In a study evaluating the P requirements of heifers, the beef NRC (2000) suggested the P requirement was 21 g P/day; in contrast, results suggested that 14.1 g/d (0.17% of DM) was sufficient (Geisert et al., 2010). Geisert et al., (2010) detected no differences in plasma P for heifers fed 0.17, 0.24, 0.31, 0.38 % P but observed plasma P levels indicative (< 4.5 mg/dL) of P deficiency in heifers fed 0.10 % P. It has been suggested that the overestimation of P requirements by the beef NRC may be due to the assumption of equal P availability across all sources, or incorrect estimations of maintenance or growth requirements (Block et al., 2004).

The maintenance and growth requirement equations developed by the beef NRC (2000) are based on absorbed P; however, a single absorption coefficient of 68 percent was assumed for all sources of P. Recommendations for dairy cattle recognize that feed and mineral sources vary in availability (Table 1; (NRC, 2001). Phosphorus availability coefficients for forages have been shown to vary from 0.35 to 0.95, 0.38 to 0.98 for concentrates and byproducts, and 0.29 to 1.00 for minerals (Sehested and Weisbjerg, 2002). It appears necessary to make use of P absorption coefficients specific to the feed or mineral source in question in order to improve P requirement recommendations, although it is unlikely that the imprecise use of absorption coefficients alone explain the difference between observed P requirements and NRC (2000) recommendations.

Phosphorus maintenance requirements are based on the endogenous loss of P measured in feces when cattle are fed at or near requirements (NRC, 2000); however there is some evidence that P excretion shifts to urine in high-concentrate diets (Scott and Buchan, 1985). Additionally, the current equation fails to take into full consideration the role of salivary production in endogenous P loss. Salivary P makes up the majority of endogenous P losses, although a small portion can be attributed to the sloughing of tissues into the digestive tract (Karn, 2001). Saliva production is influenced by eating and rumination, as well as the physical nature of the diet, with both the level of forage and the effective NDF (eNDF) influencing saliva production (Pitt et al., 1996). The data used by the NRC (2000) for determination of the P requirement was based on several studies from the 1950s and 1980s. The feedstuffs utilized differ from what is observed in a typical feedlot diet today and included higher levels of roughage. Combined, these factors have the influence to impact saliva production and potentially resulted in greater endogenous P loss than would be observed with modern diets. It has been suggested that including saliva production, as a function of DMI and eNDF, would improve the precision of P maintenance recommendations (Block et al., 2004).

Table 1. Dairy NRC (2001) phosphorus absorption coefficients for mineral sources

Item	Phosphorus absorption coefficient
Ammonium phosphate (dibasic), $(NH_4)_2HPO_4$	0.80
Ammonium phosphate (monobasic), $NH_4H_2PO_4$	0.80
Dicalcium phosphate (dibasic), $CaHPO_4$	0.85
Phosphate	0.65
Sodium phosphate (monobasic) monohydrate, $NaH_2PO_4 \bullet H_2O$	0.90
Sodium tripolyphosphate (meta and pyrophosphate, $Na_5P_3O_{10}$	0.75

Beef NRC P requirements for growth were developed using body composition data from dairy cattle published by Ellenberger et al. (1950). This method makes the assumption that there is a constant relationship between protein gain and P retention. Bone contains 80 to 90% of body P, while 60 to 85% of protein is found in soft tissue (Ellenberger et al., 1950). The lean to bone ratio in dairy cattle has been shown to be <3.4 while common beef breeds typically have ratios of 3.6 to 4.0, which suggests that the relationship between protein gain and P retention may be differ by breed (Kempster et al., 1982). Additionally, nutritional management would be expected to alter the relationship between protein gain and P retention in scenarios where cattle are maintained on a lower plane of nutrition during the growing phase and enter the feedlot with greater skeletal maturity. This is supported by data from the Nebraska trials, which found the P requirements of yearlings to be lower than that of calf-feds, 0.14 % of DM and 0.16 % of DM, respectively (Erickson et al., 1999; Erickson et al., 2002). Block et al., (2004) has proposed that P retention estimates would be improved by accounting for both skeletal growth and mineralization and soft tissue gain. Furthermore, based on P recommendations for swine (NRC, 1998) which differentiate between P required to optimize animal growth and P required for maximum skeletal mineralization, it is possible that the P requirement for cattle growth may be lower than P retention.

Although clarification of the P requirement for finishing cattle is valuable from the standpoint that it is expected to discourage provision of supplemental P, P in typical high-concentrate finishing diets exceeds P requirements due to the P contribution from basal ingredients alone. Cereal grains contain 0.25 to 0.30 % P on a DM basis while co-products such as corn gluten feed (CGF) and distillers contain (DGS) 0.95 to 1.40 % P (NRC, 2000). Discontinuing the practice of including supplemental P sources in feedlot diets will minimize the impact of excess P in the environment; however, identifying alternative methods for handling manure nutrients may be necessary in the long run for the environmental sustainability of feedlots.

Sulfur

The composition of feedlot diets has changed dramatically since the 2000 update of the beef NRC due to the rapid expansion of the ethanol industry during the 2000s. Ethanol industry expansion increased competition for corn grain and resulted in higher corn prices, but also produced corn co-products which became an oftentimes economical source of both protein and energy in feedlot diets. Although co-products such as CGS and DGS were previously utilized at low inclusion rates as a source of protein, cattle feeders used increasingly higher rates of co-products as an energy source to replace corn during times of high corn prices. Information from the Renewable Fuels Association website http://www.ethanolrfa.org/pages/industry-resources-coproducts) indicates that DGS production in 2000 was 2.7 million tons and peaked in 2011 at 39 million tons. The 2013 production was reported at 35.5 million tons, with beef cattle accounting for 48% of consumption.

Corn co-products have a number of favorable attributes as a feedstuff, but also contribute higher levels of S, compared to corn, in part due to the use of sulfuric acid to maintain fermenter pH during the ethanol production process. The beef NRC (2000) reports S (% of DM) as 0.11, 0.14, 0.40 for cracked corn, steam-flaked corn, and DGS, respectively. A greater concern than high S is the variability in S levels within and between ethanol plants. In a comparison of 6 plants which were each sampled multiple times over 4 different periods, average S content for all samples was 0.77 % on a DM basis (Buckner et al., 2011). A range of 0.90 to 1.26 %, with an average of 1.06 % and a coefficient of variation (CV) of 6.17 % was observed for one plant in a sampling period. Another plant had an average S concentration of 0.71%, but a CV of 36.3 % due to a range of 0.44 to 1.72 % S during a single sampling period. In another study, 118 DDGS samples from 10 ethanol plants were collected over 2 years in South Dakota and Minnesota, with a reported range in S concentration from 0.33 to 0.74 % and a CV within plant from 6.4 to 40.8 % (Spiehs et al., 2002). Recent changes in ethanol production methods result in a reduced-fat product, which will further concentrate S, and variability within and between plants will likely remain high as the new process is further refined. Thus, the development of nutritional and management strategies to mitigate the impact of high dietary S will remain of high priority in the foreseeable future.

High dietary S has been linked to decreases in animal performance, reduced trace mineral absorption and in cases of S toxicity the onset of polioencephalomalacia (PEM). Sulfur induced PEM is a consequence of the production of hydrogen sulfide (H_2S) in excess of ruminal capacity for absorption, resulting in an increased in H_2S dispelled during eructation (NRC, 2005). The mechanisms through which S induces PEM are not fully understood at this time, but it is speculated that eructated H_2S is inhaled and as a result bypasses hepatic detoxification and enters the brain, causing necrosis of the grey matter (Drewnoski et al., 2014). Polioencephalomalcia typically presents as a rapidly developing central nervous disorder characterized by symptoms such as ataxia, blindness, and seizures, and often results in death (NRC, 2005). Due to the negative impacts of high dietary S the interest in S hasn't been in redefining animal requirements but in characterizing the impacts of high S on animal health and performance.

The minimum requirement for S is defined by the beef NRC (2000) as 0.15% of diet DM and it has been suggested that ruminants require 0.18 to 0.24 % of DM to support microbial growth and supply essential S-containing compounds to the host animal (NRC, 2005). For practical applications, the challenge is to avoid high dietary S levels rather than meet minimum requirements. The beef NRC (2000) suggests that feedlot diets should not exceed 0.40% S. More recent recommendations define maximum tolerable limits of S in beef cattle diets as a function of forage inclusion, with a maximum concentration of 0.30 % S in diets containing less than 15 % forage and 0.50 % S for diets containing greater than 40 % forage (NRC, 2005). Additionally, the 2005 NRC recommends that water sulfate not exceed 600 ppm. These recommendations are based on a maximum level that will not inhibit intake, which is below the concentration which induces PEM. Polioencephomalacia incidence is typically determined by visual observation; however, researchers have found evidence of PEM postmortem in animals that have not shown clinical signs which suggests that actual PEM incidence is higher than reported (Niles et al., 2002).

Although feed S tends to get greater attention, the contribution of S from drinking water must also be taken into consideration when balancing feedlot rations. Sulfur in water is in the form of sulfates, which are 35% S; thus, water with 600 ppm sulfate would contribute 210 ppm S. Water sulfates may be highly variable and is specific to each site. The 1999 USDA APHIS feedlot survey reported that the majority of feedlots submitting water samples, which represented 10 states, had sulfate levels less than 300 ppm; however, 7.7 % of feedlot surveyed had sulfate concentrations greater than 1000 ppm. Research has suggested that water sulfate concentrations of 1000 ppm are generally safe (Wright, 2007) and the NRC (2005) suggests that water sulfate in beef cattle diets be limited to 600 ppm. Using the NRC (2005) recommendation for maximum tolerable S limit of 0.30 % DM for a high-concentrate diet with water sulfate at 600 ppm the total S intake would be 0.38 % for a 1200 lb steer consuming 14.5 gallons of water/d and a diet consisting of 55 % DRC (0.14 % S), 30% WDGS (0.7 % S), 10 % corn stalks (0.14 % S) and 5 % supplement (0 % S).

Computing maximum tolerable S levels on dietary S alone fails to take into account the biological process involved in the production of H_2S. Hydrogen sulfide production is dependent on the availability of sulfate to sulfate reducing bacteria (Drewnoski et al., 2014). Ruminal availability of S varies depending on source; as such, it has been suggested that adjusted ruminal protein S (ARPS) is a better predictor of H_2S concentration than dietary S (Sarturi et al., 2013a)(Nichols et al., 2012). Inorganic sources of S are 100 % available, while S-AA will vary in availability due to the fractionation of protein degradation and the incorporation of some S-AA in microbial protein. Coefficients for ARPS were determined by estimating the percent organic S from S-amino acids, which was multiplied by undegradable intake protein which results in the percent undegradable S intake. This value was subtracted from total S, resulting in a value for ARPS. The same equation was used by Nichols et al. (2013), although the resulting value is referred to as ruminally degradable S (RDS) in this study. Values for RDS for common feedstuffs, as reported by Nichols et al. (2012), are shown in Table 2. Sarturi et al. (2013) reported that ARPS intake accounted for a greater portion of the variation in ruminal H_2S concentration than S intake (58 vs. 29 %, respectively).

The relationship between level of sulfur and forage NDF was defined in a recent meta-analysis, which found that for a given level of RDS risk of PEM decreased approximately 19 % for each 1 % increase in roughage NDF in the diet (Nichols et al., 2012). The incidence of PEM in cattle consuming diets of 0.5 % S and 4 % NDF was found to be about 1 % and a recommendation to not exceed 0.46 % dietary S, in scenarios where water sulfate is low, was suggested. The relationship between PEM and NDF may be partially explained by rumen pH. Diets high in readily fermentable carbohydrates, such as the typical high-concentrate feedlot diet, result in the rapid production of volatile fatty acids (VFA) and lactic acid. Production of VFA and lactic acid at rates above the rumen's capacity for removal, via absorption across the rumen epithelium and outflow through the reticular-omasal orifice, results in decreased rumen pH, which has been suggested to increase the amount of sulfide that remains as H_2S (Drewnoski et al., 2014). Several experiments have shown a negative linear relationship between ruminal pH, as influenced by varying levels forage NDF inclusion, and ruminal H_2S concentration (Morine et al., 2012; Morrow et al., 2013; Morine et al., 2014). In contrast, other researchers have found rumen pH to be a poor indicator of ruminal metabolism changes induced by S levels (Sarturi et al., 2013b). Morrow et al., (2013) reported no differences in cattle performance as a consequence of forage NDF level and Morine et al., (2012) observed no differences in average daily gain, although dry matter intake increased with increased forage NDF, which collectively suggest that increased forage NDF may decrease the risk for PEM but does not appear to improve cattle performance.

Table 2. Rumen degradable sulfur (RDS) for common feedstuffs[1].

Feedstuff	Sulfur (% of DM)	RDS (% of DM)	% RDS of total S
Alfalfa hay	0.21	0.19	90.4
Condensed corn distillers solubles	1.12	1.08	96.4
Corn gluten meal	0.72	0.21	29.2
Cornstalks	0.20	0.18	90.0
Dried distiller grains w/ solubles	0.76	0.52	68.4
Dry rolled corn	0.14	0.06	42.9
Grass hay	0.18	0.16	88.9
Steam flaked corn	0.14	0.06	42.9
Wet distillers grains w/ solubles	0.81	0.56	69.1

[1]Data reported by Nichols et al., 2012.

Although minimum animal requirements for S are not clearly defined, typical feedlot diets provide S well in excess of the requirement. Instead, a continued focus on developing approaches for determining maximum S levels based on the underlying biological mechanisms that drive the negative impacts of high S are warranted as a continued reliance on corn co-products as a feedstuff for feedlot cattle is likely for the foreseeable future. Further research will be necessary in this area to identify and refine the best method for this determination; however, methods based on the ruminal availability of S for reduction to H_2S currently shows promise.

Trace Minerals

Trace minerals are required by cattle in small amounts and are typically expressed in feed on a concentration basis, as compared to macro-minerals which are generally expressed as a percentage of diet DM. The trace minerals which have been identified as essential for beef cattle are of iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), selenium (Se), cobalt (Co), iodine (I), chromium (Cr), molybdenum (Mo) and nickel (Ni). Recent trace mineral research in beef cattle has primarily focused on Cr, Co, Cu, and Zn.

Chromium

At the time of the NRC (2000) publication, insufficient data was available for the determination of the Cr requirements for beef cattle. New research has been subsequently generated; however, there remains a scarcity of data available in feedlot cattle. Chromium functions as a component of the glucose tolerance factor that potentiates the action of insulin (Mertz, 1992) and chromium deficiency has been linked with insulin resistance and impaired glucose tolerance (Sumner et al., 2007).

Historical Cr research reveals inconsistent improvements in glucose clearance in growing animals (Bunting et al., 1994; Kegley and Spears, 1995; Kegley et al., 1997; Depew et al., 1998; Bunting et al., 2000); however, more recent work in growing, lactating, and pregnant cattle utilizing organic sources Cr, such as Cr methionine or Cr propionate, have been more consistent (Hayirli et al., 2001; McNamara and Valdez, 2005; Sumner et al., 2007; Spears et al., 2012). The FDA issued a regulatory discretion letter in 2006 allowing supplemental Cr up to 0.5 mg/kg of DM in the form of Cr propionate. It is possible that determination of a Cr recommendation was hindered in the past by inconsistencies from comparing Cr from different sources with differing bioavailability.

Insulin sensitivity and glucose clearance has been shown to be increased by supplementation of Cr propionate in growing beef and dairy heifers following i.v. glucose administration (Sumner et al., 2007; Spears et al., 2012). The proposed mechanism for increased glucose clearance involves the binding of Cr with a low molecular weight peptide resulting in increased translocation of glucose transporters to the cell membrane (Cefalu et al., 2002). Spears et al., (2012) provided 0, 3, 6, or 9 mg supplement Cr/d in the form of Cr propionate, which corresponded to 0.20, 0.47, 0.94 and 1.42 mg of supplemental Cr/kg of DM, and observed increased insulin sensitivity and lower molar ratios of insulin to glucose following a glucose challenge with all levels of Cr supplementation. Spears and coworkers (2012) concluded that the Cr requirements of growing beef heifers can be met by provision of 0.47 mg of supplemental Cr/kg of DM. Sumner et al., (2007) observed a 36 % increase in glucose clearance across all Cr treatments, as compared to control, with supplementation of 5, 10, and 15 mg/d of Cr propionate in dairy heifers. Dry matter intake was not reported for this study and consequently supplemental Cr intake as a function of dry matter intake was not available. In another study, Cr propionate was fed during a 56-d receiving period at 0, 0.1, 0.2 or 0.3 mg/kg of DM resulting in a linear increase in ADG and feed efficiency (Bernhard et al., 2012). Additionally, Cr supplementation attenuated body weight loss following a lipopolysaccharide challenge. The authors suggested that supplementation of Cr propionate at 0.3 mg/kg of DM can reduce the costs associated with morbidity during the receiving phase and improve feed efficiency and growth performance.

Consistency of animal response to supplemental Cr has improved with use of Cr propionate; however further research into the impact of supplemental Cr in finishing cattle specifically will be necessary to identify a requirement. Synthesis of a Cr recommendation would be valuable in light of the role Cr plays in insulin and glucose regulation as well as immunity.

Cobalt

Cobalt functions as a component of vitamin B_{12}, which is synthesized by rumen microorganisms. Vitamin B_{12} dependent enzymes present in mammalian tissue are methylmalonyl CoA mutase, which is important for the metabolism of propionate to succinate, and 5-methyltetrahydrofolate homocysteine methyltransferase, which is involved in the recycling of methionine following transfer of it methyl group (McDowell, 2008). The beef NRC (2000) defines the Co requirement for beef cattle as approximately 0.10 mg/kg DM.

A long-term study of the dietary Co requirements of Simmental cattle based on maximal plasma and liver vitamin B_{12} estimated requirements to be 0.26 and 0.24 mg/kf of DM, respectively (Stangl et al., 2000). Cattle were fed corn silage ad libitum and 2.5 kg/d of an energy protein for 280 d with total Co concentration ranging from 0.07 to 0.69 mg/kg of DM. In a second study of

Simmental cattle, Co requirements were determined by regression analysis to be 0.12 mg/kg for maximal body weight gain and 0.16 to 0.18 mg/kg DM for maximal feed intake (Schwarz et al., 2000). Basal diet and dietary Co concentrations were the same as described for Stangl et al., (2000).

Cobalt requirements of growing and finishing Angus and Angus-cross steers fed low Co diets (0.04 to 0.05 mg Co/kg of DM) showed no differences in growth performance during the growing phase with supplemental Co levels of 0, 0.05, 0.10 and 1.0 mg/kg of DM (Tiffany et al., 2003). During the finishing phase, responses to supplement Co were greater during the early portion of the feeding period. Higher feed intake was observed in steers supplemented with 1.0 mg Co/kg of DM; however, the addition of 0.05 mg Co/kg of DM, a total dietary Co of 0.09 mg/kg of DM, appeared to be sufficient for maximal gain and feed efficiency. Increasing supplemental Co above 0.05 mg/kg DM resulted in a linear increase in plasma vitamin B_{12} and quadratic increase in liver B_{12} which led Tiffany et al., (2003) to suggest that the Co requirement for finishing cattle is 0.15 mg/kg of diet DM.

These studies suggest that the Co requirement for finishing cattle may be too low when using B_{12} status as the measure; however, animal performance responses suggest that 0.10 mg Co/kg of DM may be sufficient or only slightly marginal.

Copper

Copper is an essential component of a number of enzymes involved in nucleotide and vitamin metabolism and is also involved in neutrophil functions and acute phase protein ceruloplasmin, among other functions (Minatel and Carfagnini, 2000). The NRC (2000) indicates that 10 mg of Cu/kg of DM should be sufficient for beef cattle in situations where dietary S does not exceed 0.25 % of DM and Mo doesn't exceed 2 mg/kg. Copper requirements are greatly influenced by the presence of antagonists in the diet. High dietary concentrations of Mo, Cu and S have all been shown to influence Cu availability (NRC, 2005). Additionally, data suggests that breed also influences Cu requirements. Simmental and Charolais appear to have a higher minimum Cu requirement than Angus cattle (Ward et al., 1995; Mullis et al., 2003). Lower expression of mRNA of transporters involved in Cu absorption has been observed in pregnant Simmental cows, as compared to Angus cows (Fry et al., 2013).

Copper supplementation of corn-based finishing diets has been inconsistent. Intake and gain was increased by 20 mg/kg of DM Cu supplementation in finishing steers fed a control diet containing 0.28 % S, 4.9 mg of Cu, and 0.6 mg of Mo/kg of DM (Engle et al., 2000b). In contrast, Simmental steers supplemented with 10 or 20 mg Cu/kg of DM exhibited increased Cu status but did not differ from control steers in growth performance, carcass characteristics, or lipid metabolism (Engle and Spears, 2001). Similarly, Cu had no impact of growth performance or intake when supplemented at 10 or 20 mg/kg of DM in a diet containing 4.9 mg Cu/kg DM, although lipid and cholesterol metabolism was impacted by both levels of supplementation (Engle and Spears, 2000). Growth performance and feed intake were not impacted by 20 mg Cu/kg of DM supplementation in Angus steers fed a high-concentrate diet containing 5.2 mg Cu/kg of DM, although a reduction in back fat was observed (Engle et al., 2000a). Dry matter intake, average daily gain and gain efficiency was reduced in finishing steers that were fed a grower diet containing 10.2 mg of Cu for 56 d and then transitioned to a finisher diet containing 4.9 mg Cu/kg of DM that was supplemented with 20 or 40 mg Cu/kg of DM (Engle and Spears, 2000; Engle and Spears, 2000).

Zinc

Zinc is a component of enzymes involved in protein, nucleic acid, carbohydrate, and lipid metabolism and is also involved in cell membrane stability, immunity, and gene expression. The beef NRC (2000) suggests that the Zn requirement is 30 mg/ kg of DM. Performance responses to supplemental Zn have been variable in finishing and growing cattle. Inconsistency in performance and carcass characteristic responses to supplemental Zn may be explained by differences in Zn source and subsequent bioavailability; however, further research will be necessary in this area to make any definitive conclusions.

Finishing steers supplemented with 20, 100, or 200 mg Zn/kg of DM did not differ in growth performance from controls, although fat thickness and quality grade increased in a quadratic fashion with increasing Zn, when fed a basal diet containing 90 mg Zn/kg of DM (Malcolm-Callis et al., 2000). It should be noted that in this study the Zn concentration in the basal diet exceeded the beef NRC (2000) recommendation by three-fold. In a comparison of inorganic and organic Zn sources supplemented at a rate of 25 mg Zn/kg of DM to a diet containing 26 mg Zn/kg DM, growth performance of finishing steers was not impacted, regardless of Zn source, but steers fed organic Zn had heaver hot carcass weights and slightly higher dressing percentages than those in the control or inorganic treatment groups (Spears and Kegley, 2002). In contrast, finishing heifers supplemented 75 mg of Zn/kg of DM on a diet of 50.5 mg Zn/kg of DM tended to gain more and have improved gain efficiency but did not display any differences in carcass characteristics compared to control heifers (Nunnery et al., 2007).
In growing cattle, supplementation with 25 mg of Zn/kg of DM, from organic or inorganic sources, to a corn-silage based diet containing 33 mg Zn/kg of DM increased the ADG of steers regardless of Zn source (Spears and Kegley, 2002). In a 28 d study performance did not differ with supplementation of 360 mg Zn/d from organic and organic sources in growing calves (Kegley et al., 2001). Similarly, supplementation of Holstein calves with 20 mg of Zn/kg of DM did not impact growth (Wright and Spears, 2004).

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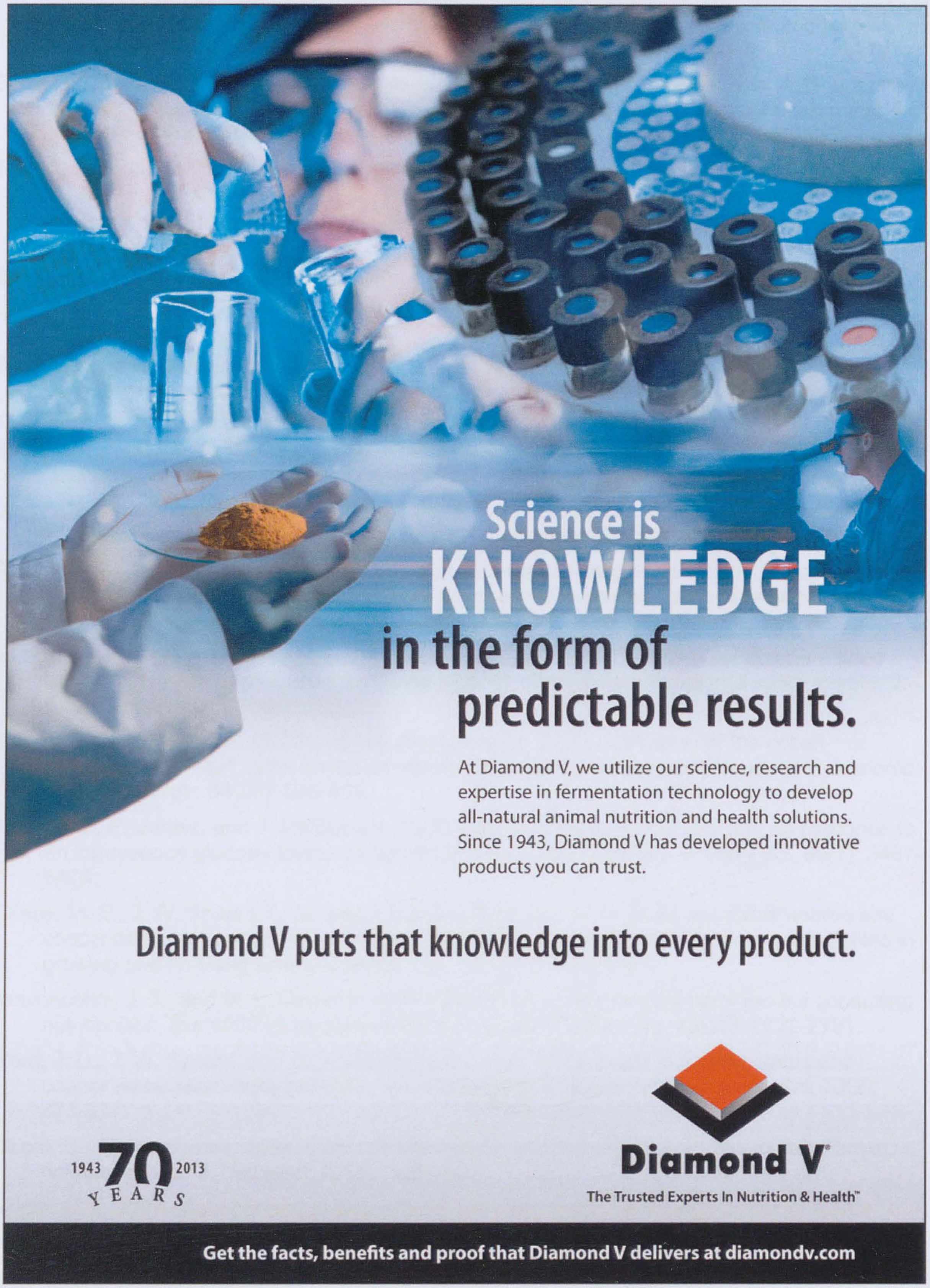
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